COLOR DIAGRAMS FOR NON VACUUM REGGEONS IN HADRON-HADRON INTERACTIONS

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Abstract

One-to-one correspondence between dual diagrams of dual resonance model and QCD based color diagrams describing non vacuum exchanges in $\pi^+\pi^-$, $\pi^\pm p$, $p\bar{p}$ interactions is discussed. Both for dual and color diagrams there are state with quark-antiquark in t channel and state, in which only coherent quark string exists, in s channel. There are no such dual diagrams in pp interaction. Color diagram for pp interaction was found basing on principle of conformity. Secondary hadrons spectrum, obtained from this diagram, has nucleon in its central region. This effect may lead to increase of baryon chemical potential in nucleus-nucleus collisions in facilities NICA and FAIR.

1 Introduction

Processes with multiple production at high energies are intensively studied both experimentally and theoretically. At that time behavior of multiple processes at low energies $\sqrt{s} \approx 2 - 5$ GeV is known much less. It is believed now that nucleus-nucleus collisions at low energies may sooner lead to discovery of phase transition from hadronic matter to the quark-gluon plasma than nucleus-nucleus collisions at high energies.

Multiple processes at low energies are dominated by contributions of non vacuum reggeons. While “pomeron physics” is considerably well explored basing on QCD ([1] – [6], also see [7] and references therein) clear QCD based picture of multiple processes, associated with non vacuum reggeons is still missing.

In present work we will study out which “color diagrams” correspond to non vacuum reggeons. Analysis of these color diagrams will show that at low energies baryon number increase in central region of produced particles spectrum. For nucleus-nucleus collisions it means that baryon chemical potential is increased in central region of spectrum. This may lead to discovery of phase transition to quark-gluon plasma at energies of facilities NICA and FAIR.

Here we use Okubo basis for $SU(3)$ group. In this basis quark and antiquark lines are solid colored lines (red, blue and green), gluon lines are double dotted lines (see Fig. 1). Direction of color is preserved.

Quark and antiquark lines are continuous, breakup is shown to indicate direction of color. Gluons are non diagonal and coincide with gluons in Okubo basis for $U(3)$ group. Diagonal gluons which are characteristic for $SU(3)$ group will be introduced later. Summing up all color lines is implied in what follows.

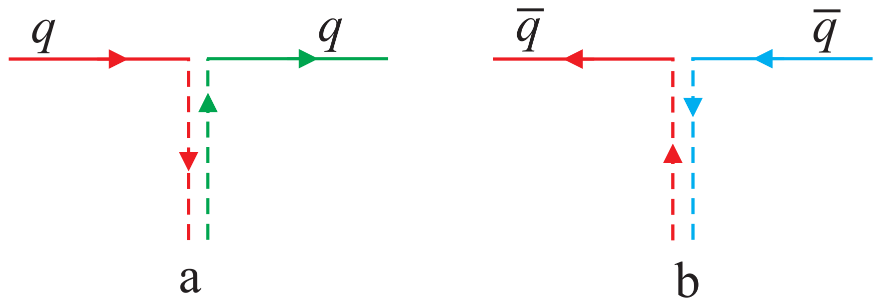

Figure 1: Interaction vertices of quark with gluon (a) and antiquark with gluon (b).

2 Dually topological diagrams

Hadrons interactions with exchange of non vacuum reggeon correspond to soft processes with flavor transfer in t channel. Since only slow partons softly interact with each other, initial state configurations where one of valence quarks has low momentum are very essential.

In frame of dual resonance model ([8] – [11]) slowing of quark and reggeon exchange is depicted as dual diagram in Fig. 2 (we consider $\pi^+\pi^-$ scattering).

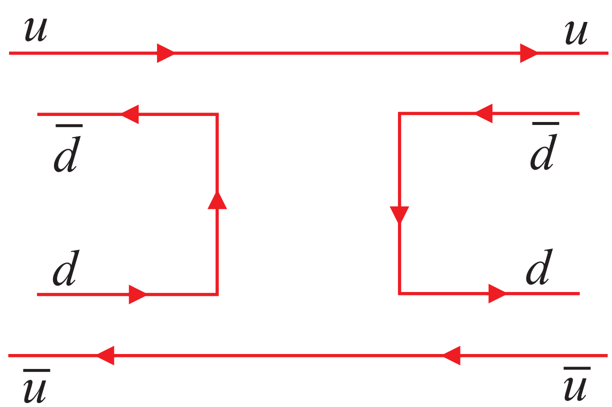

Figure 2: Dual diagram for $\pi^+\pi^-$ scattering

In this approach hadrons (mesons) represent string with quark and antiquark at its endpoints. When moving in 4-dimensional space-time string sweeps out 2-dimensional surface. Diagram in Fig. 2 shows elastic interaction. String endpoints of initial state merge and further one quark string moves in s channel, which then splits into two strings. Consequently elastic scattering amplitude appears, which constitutes smooth 2-dimensional surface. The same 2-dimensional surfaces correspond to amplitudes of n particles production. More complicated structure, in which hollow cylinder is glued to poles that are swept out by strings of initial hadrons, corresponds to pomeron.

Dual resonance model gives independent inference of reggeon diagram technique, which does not use expansion in colorless particles of amplitudes or parton wave functions. The AGK theorem [12] may be obtained also in frame of this approach [7]. Dual diagrams for π^+p and $p\bar{p}$ interactions are given in Fig. 3 and 4.

In case of $\pi^{\pm}p$ interaction there is stage when only quark string moves in s channel, similarly to diagram in Fig. 2. Endpoints of this string are quark and diquark.

In case of $p\bar{p}$ interaction region is swept out by string with quark and diquark at its endpoints.

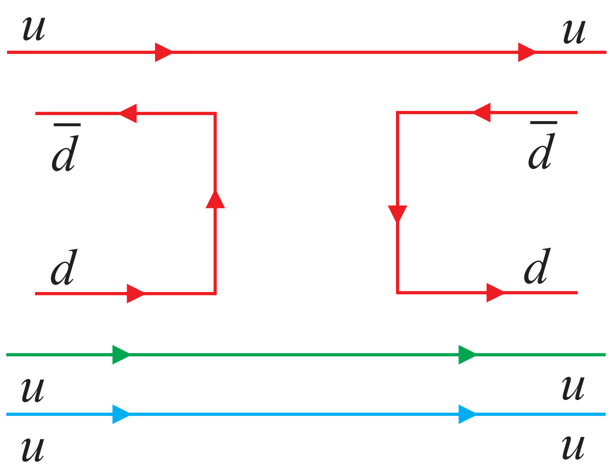

Figure 3: Dual diagrams for $\pi^+ p$ interaction. Completely analogous diagram can be drawn for $\pi^- p$ scattering.

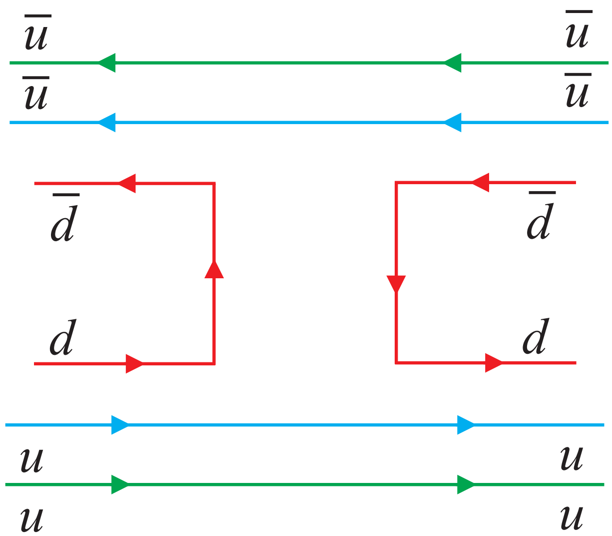

Figure 4: Dual diagram for $p\bar{p}$ scattering.

In what follows we will construct color diagrams for non vacuum reggeons using two results, obtained from consideration of dual diagrams DRM.

1. In s channel of color diagrams there must exist quark string, which is not divided into several parts. This string has quarks (antiquarks) and diquarks (antidiquarks) at its endpoints.

2. In t channel elastic amplitudes, describing reggeon contributions, must have quark-antiquark pair.

3 Color diagrams

We will construct color diagrams for non vacuum reggeons likewise construction of color diagrams for vacuum exchange [5].

At first we will consider $\pi^+\pi^-$ scattering (Fig. 5).

Transfer of color string into secondary hadrons has probability equal to one, because color objects can not be observed in final state. Therefore square of diagram module from Fig. 5c is shown in Fig. 6.

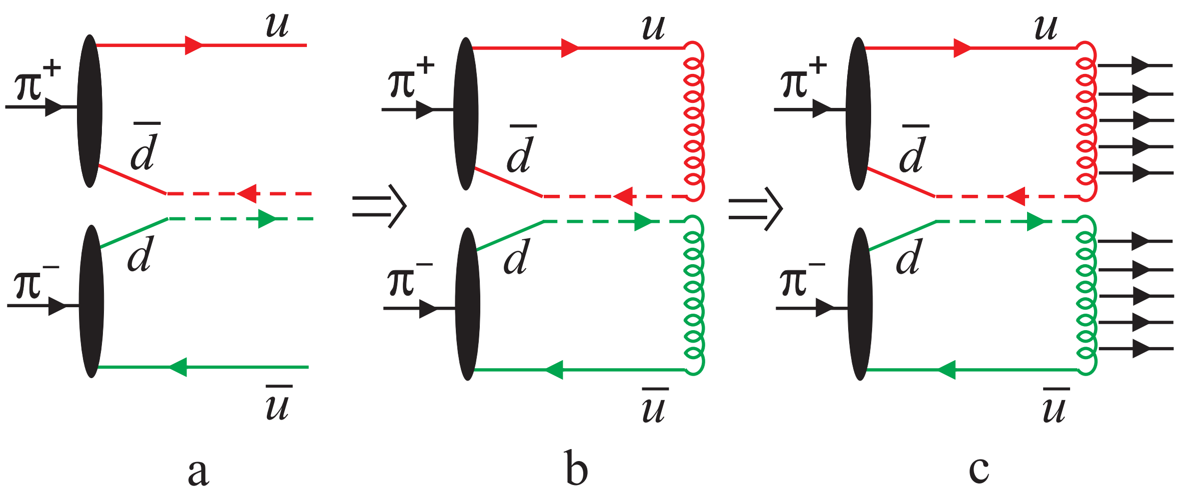

Figure 5: Slow in center-of-mass system quark d and antiquark $\bar{d}$ annihilate to gluon (a). When quark u and antiquark $\bar{u}$ move apart, color field string appears (string is shown as spiral), which is recharged by gluon (b). Then this string breaks out into secondary hadrons (c).

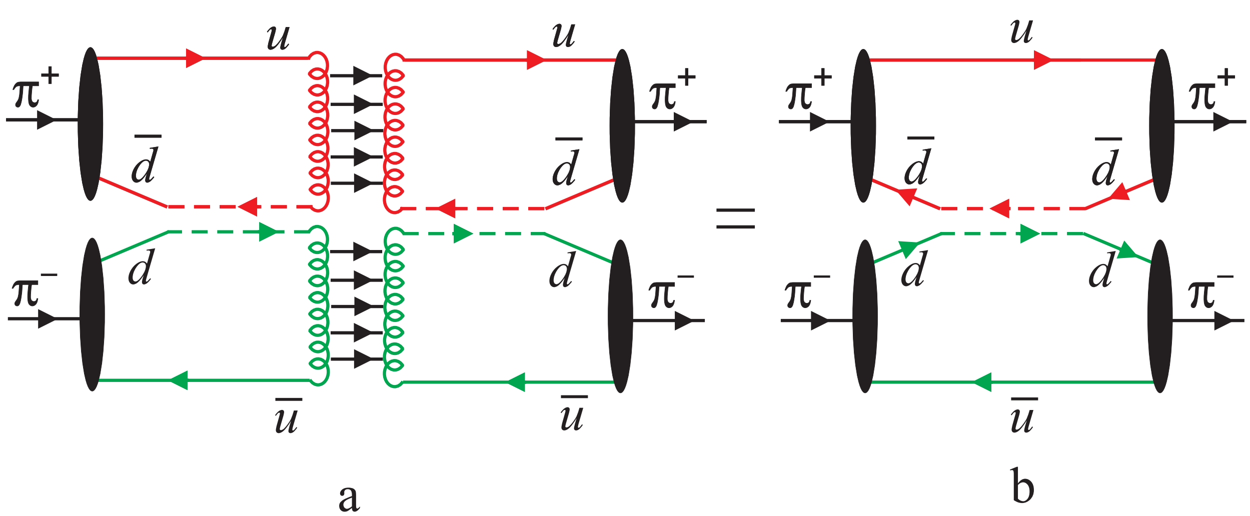

Figure 6: Square of diagram module from Fig. 5c.

Transfer from diagram in Fig. 6a to diagram in Fig. 6b is proved just like transfer to diagram of two gluons exchange in [5].

Let us compare diagrams in Fig. 6 with diagram in Fig. 2. Both for dual diagram in Fig. 2 and color diagrams in Fig. 6 we can state the following.

1. There is quark string in s channel with quark and antiquark at its endpoints. Since gluon is pointlike particle, it can only recharge (recolor) string, but not to split it into two strings (Fig. 6a).

2. There is quark-antiquark state in t channel (Fig. 6b).

Consequently we have one-to-one correspondence between dual diagrams in Fig. 2 and color diagrams in Fig. 6. There is the same one-to-one correspondence between dual and color diagrams for $\pi^+ p$ and $p\bar{p}$ interactions.

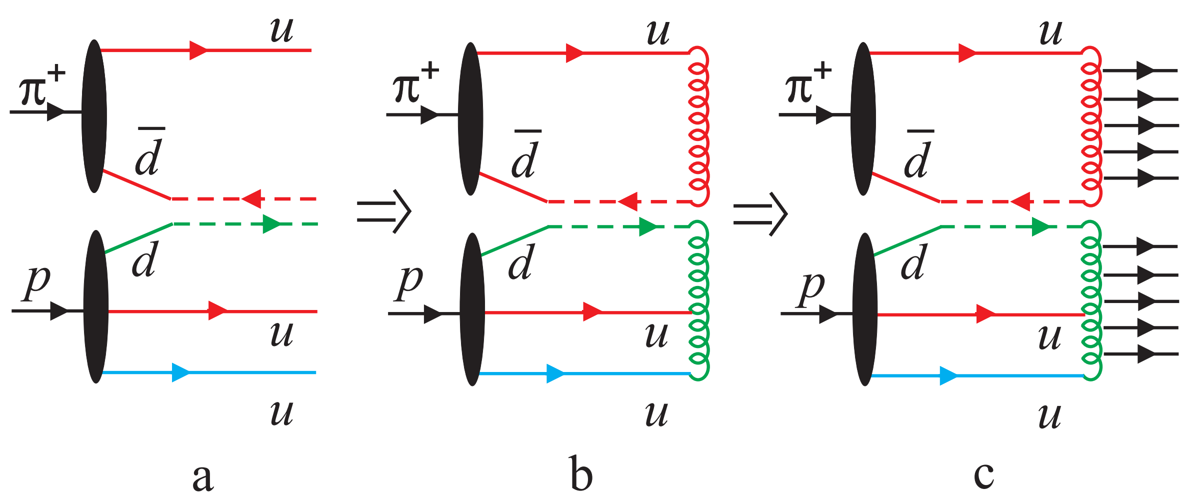

Figure 7: $\pi^+ p$ interaction.

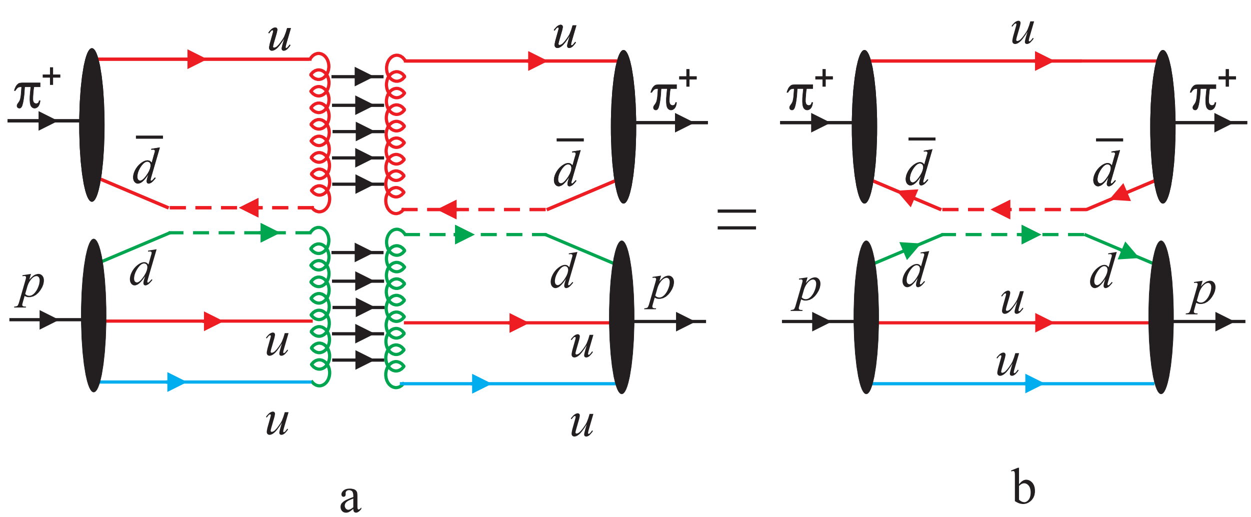

Figure 8: Square of diagram module from Fig. 7c. (a) String in s channel has quark and diquark at its endpoints. (b) Elastic amplitude in t channel contains quark-antiquark state.

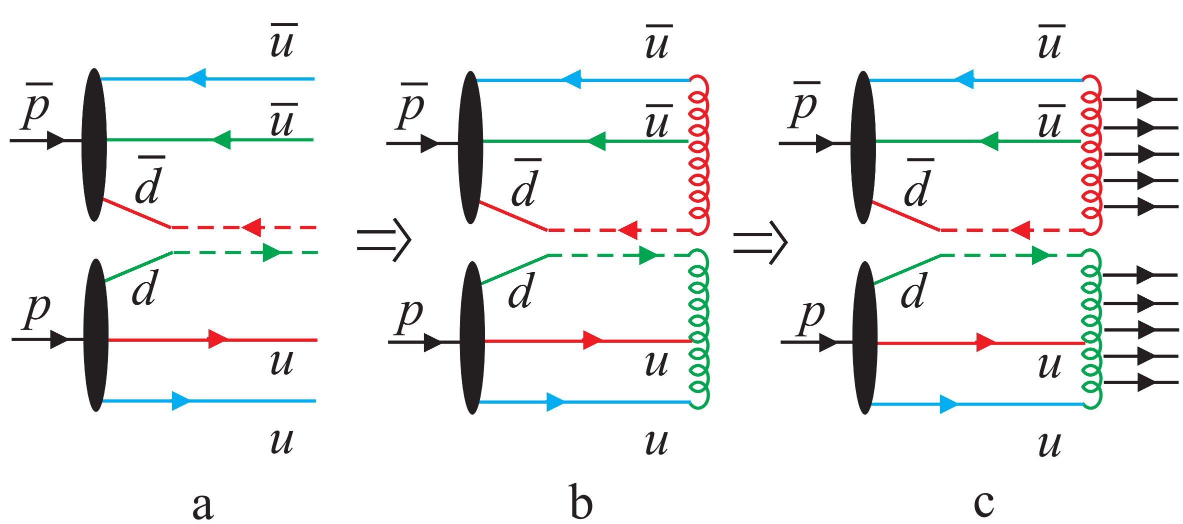

Figure 9: $p\bar{p}$ interaction.

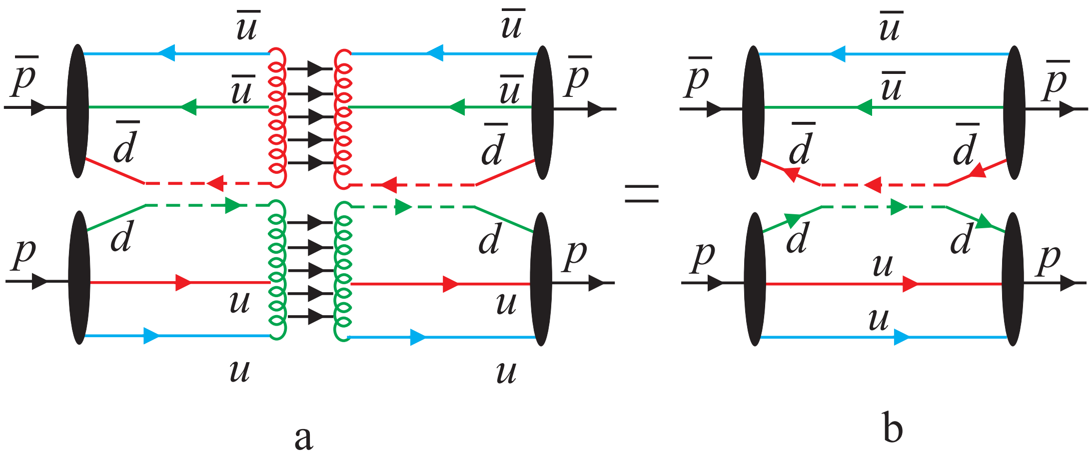

Figure 10: Square of diagram module from Fig. 9c. (a) String propagates in s channel. Its endpoints are antidiquark and diquark. (b) There is quark-antiquark state in t channel.

In both cases of $\pi^+ p$ and $p\bar{p}$ scatterings there is one-to-one correspondence between dual and color diagrams.

4 Color diagrams for nucleon-nucleon scattering

There are no dual diagrams for nucleon-nucleon collisions (we will consider proton-proton scattering as example). This process is described by so-called twist diagrams, in which scattering of slowed quarks takes place, but not annihilation of quark and antiquark. In the first approximation of DRM such diagrams do not contribute to imaginary part of nucleon-nucleon scattering. So non vacuum Regge contributions which are present in meson-nucleon and antinucleon-nucleon interactions must not exist in case of nucleon-nucleon interactions. But these contributions are visible in experimental data and parameters of their Regge trajectories (intercepts and slopes) coincide with Regge trajectories parameters of $\pi^{\pm}p$, $K^{\pm}p$, $p\bar{p}$, $n\bar{p}$ collisions.

Therefore there must exist a diagram which fulfills requirements of dual diagrams. We have found two diagrams of process with one quark string in s channel, Fig. 11.

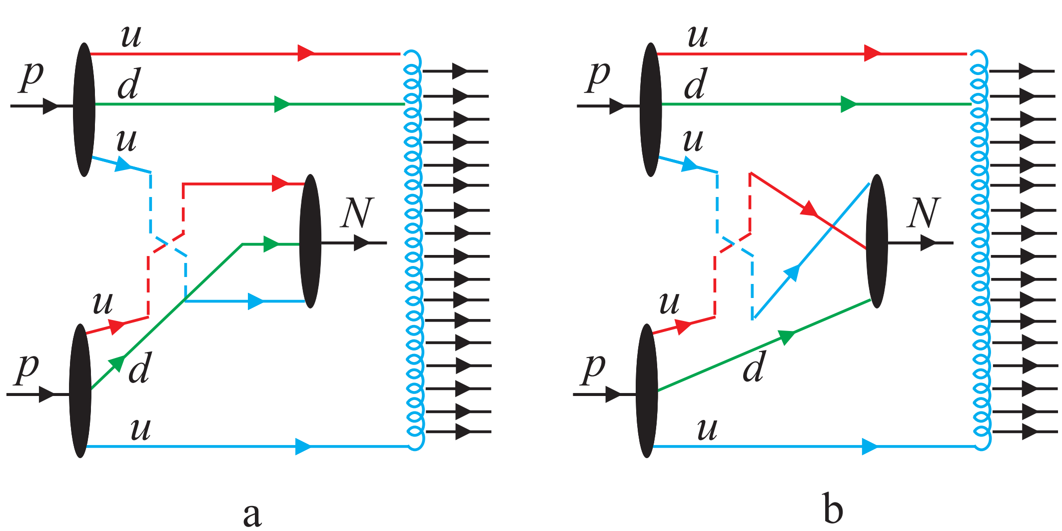

Figure 11: pp interaction.

In diagram from Fig. 11a quarks move forward after scattering, in diagram from Fig. 11b they move backward. In order to form one quark string in s channel one of protons must be taken in configuration with slowed diquark. String in s channel has quark and diquark at its endpoints. Since this string breaks out into secondary hadrons, then slow state with three quarks also forms colorless state – some baryonic resonance.

Configuration with slow quarks in each proton, as shown for example in Fig. 12, leads to production of two separated in space quark strings and does not meet the selected principle of conformity.

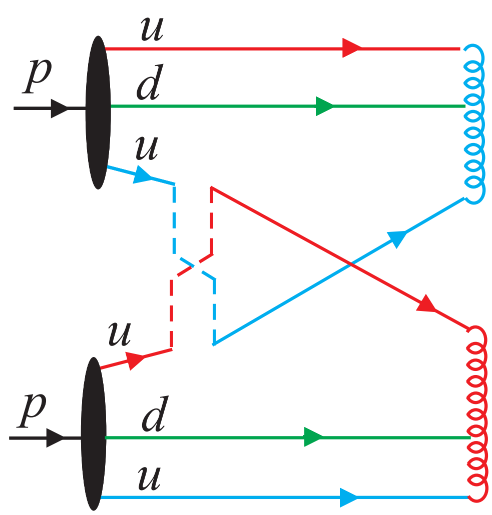

Figure 12: pp interaction.

Square of diagram module from Fig. 11a corresponds to two gluons exchange in t channel and, possibly, it can be described by trajectory of some f-resonances-glueballs. Square of diagram module from Fig. 11b corresponds in t channel to state 2 quarks + 2 antiquarks and is described by low lying non vacuum trajectory. The only diagram of elastic scattering, which has one quark string in s channel and quark-antiquark state in t channel, is interference contribution of diagrams from Fig. 11a and Fig. 11b, it is shown in Fig. 13.

Thus we can argue that leading non vacuum reggeons in nucleon-nucleon scattering (proton-proton, proton-neutron and neutron-neutron) result in translocating of baryons from fragmentation region to central region of secondary hadrons spectrum.

5 Conclusion

The obtained result means that in nucleus-nucleus scattering at low and intermediate energies baryon number may increase in central region of secondary hadrons spectrum. This may help in discovering quark-gluon plasma effects in facilities NICA and FAIR.

We have come to conclusions by studying structure of color diagrams for non vacuum reggeons. Evidently, further detailed analysis is necessary. Though many important results were obtained only from structure of diagrams in $\lambda\varphi^3$ theory. In particular, the first proof of the AGK theorem was derived exactly from analysis of ladder diagram structure in $\lambda\varphi^3$.

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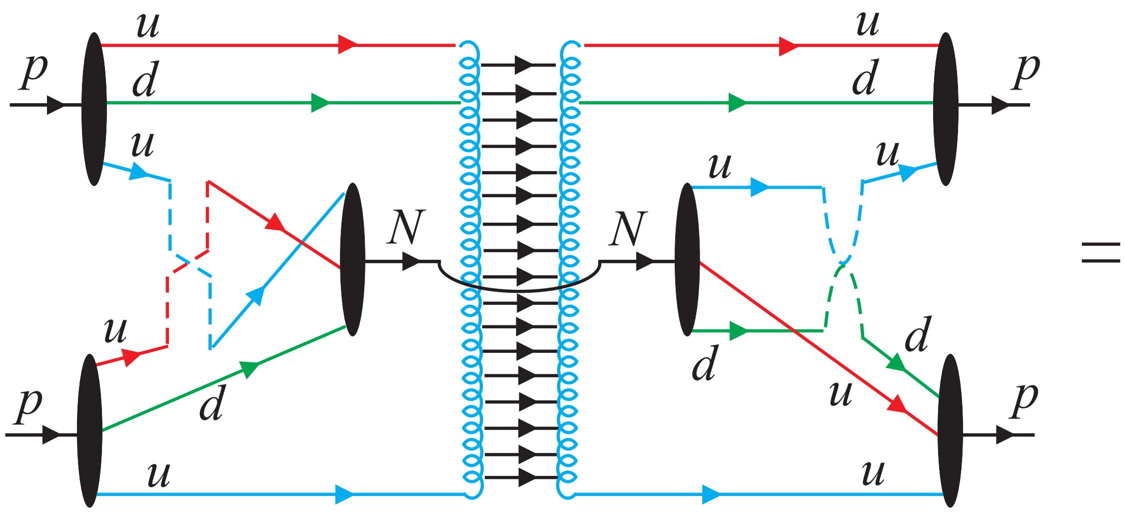

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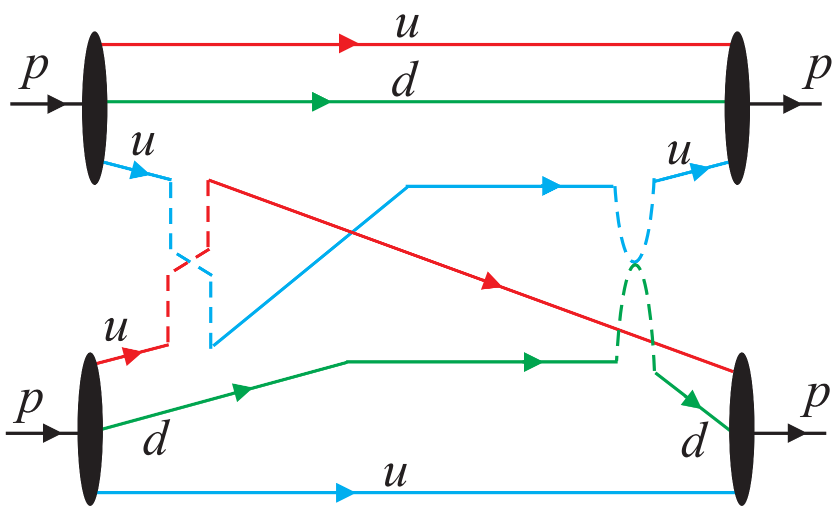

b

Figure 13: (a) One quark string in s channel. (b) Quark-antiquark state in t channel. Diagonal gluons exchange in Okubo basis for $U(3)$ group is shown in right side.

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